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Genetic Variability in Grain Nitrogen Content of Rice as Affected by Soil Moisture and Fertilizer

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Summary

The negative correlation which is generally observed between grain nitrogen content (GNC) and harvest index (HI) was decreased by a *Japonica-Indica* hybrid, Josaeng Tong-il which showed both high GNC and HI. An upland cultivar, Sankanka, showed promise as a line to be used as a genetic resource due to its persistently high GNC even at low fertilizer levels. Although the straw nitrogen content (SNC) did not show any relationship with GNC at the harvesting stage, the total straw nitrogen content showed a positive correlation, indicating that cultivars with the larger nitrogen stock capacity of the straw may translocate the higher amount of nitrogen to the grains.

Introduction

If one considers the number of people depending on the crops for their daily carbohydrate and protein requirement, and the area under cultivation, rice (*Oryza sativa* L.) is clearly one of the most important food crops in the world. The protein of rice is one of the most nutritious among the cereals[8], i. e. well-balanced amino acid composition. However, unfortunately, the protein content is relatively low (7％ at 14％ brown rice moisture content). Protein content in rice depends on a number of factors such as genetic traits of cultivars, environmental conditions and cultural practices.

The application of nitrogen fertilizer is known to increase both the yield and protein content of rice[3,4]. Generally, it is well known that rice yields tend to be lower under upland than flooded conditions[2]. However, investigations on the relation of protein content of rice to soil moisture are lacking. Thus, the varietal variations in the capacity of the rice plant to increase grain protein content with different levels of fertilizer applied periodically after flowering under upland and flooded conditions were investigated.

Materials and Methods

The experiment was conducted in the glass-house at the Faculty of Agriculture of Yamagata University in Tsuruoka, Japan. Two *Japonica*, two *Indica*, two *Javanica* and two upland cultivars were used. Plants were grown in pots of 16 cm diameter and 20 cm deep (1/5,000 a). Each treatment consisted of three replicates which were randomized. Four grams of a basal fertilizer containing N : P_2O_5 : K_2O in the percentage of 13 : 13 : 13 were added to each pot at puddling. All the plants were initially grown under the same soil moisture of 2～3 cm depth of standing water. The different treatments of fertilizer supply and soil moisture were commenced after the initiation of flowering. Of the 18 pots of each cultivar, nine pots were subjected to upland conditions (20～40 cmHg) and 9 pots to flooded conditions. Of the 9 pots under each moisture level, three pots received no nitrogen fertilizer (ON plot), three pots received 5 m*l* of ammonium sulphate solution (2.5 kg/10 a ; 1 N plot) and

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three pots received 10 ml of ammonium sulphate solution (5.0 kg/10 a ; 2 N plot). The treatments were repeated weekly upto harvest. Harvesting was done on the seventh week after flowering. Samples were then oven-dried and the grain and straw weights determined. Grain and straw nitrogen contents were determined by the semi-micro Kjeldahl method.

Results and Discussion

The ripening percentage tended to increase with fertilizer level under upland conditions, but did not show much variation under flooded conditions (Table 1). The high sterility percentage of the upland cultivar, Sankanka, could also be a reason for its exceptionally high GNC (Fig. 1), although earlier experiments (unpublished) had also shown that Sankanka had high GNC when the ripening percentage was relatively high. However, a *Javanica* cultivar, Stirpe 136 Anthocyane which showed the high sterility in the low fertilizer level under upland conditions had low GNC. Thus, the high GNCs of Sankanka in all the conditions may reflect a large genetic contribution together with sink-source balance.

As in the many investigations which were reported hitherto[5, 9, 10], the HI tended to negatively correlate with GNC in three fertilizer levels in combination with two soil moisture levels although significantly only in two cases (Fig. 1). In contrast with the high GNC and the low HI of an upland cultivar, Sankanka, two *Japonica* cultivars, Akihikari and Sasanishiki, showed the low GNC with the high HI in all the conditions. On the other hand, a *Japonica–Indica* hybrid, Josaeng Tong-il showed a high GNC although the HI was almost the same level as the two *Japonica* cultivars in all the conditions. This extremely high value of GNC of the *Japonica–Indica* hybrid seems to contribute to reduce the correlation of GNC to HI. The present results excluding Josaeng Tong-il showed highly negative correlations between GNC and HI (Fig. 1). This is in agreement with the suggestion of HIGASHI *et al.* (1974), where the decrease of GNC with increase of HI was ascribed to a "dilution effect"

Table 1. Varietal variations in ripening percentage at the different soil moisture and fertilizer levels.

Cultivar or strain	Heading date	Ripening percentage (%)					
		Moisture level					
		Upland			Flooded		
		Fertilizer level*1					
		0 N	1 N	2 N	0 N	1 N	2 N
1. Akihikari	7/31	77.7*2 3.8*3	86.1 3.3	88.7 2.3	91.8 1.2	89.1 1.4	92.2 2.0
2. Sasanishiki	8/13	87.0 1.6	91.3 2.1	94.7 0.3	86.5 1.4	92.0 1.0	93.4 1.5
3. Mao-zu-tao	8/11	85.6 1.8	94.1 0.6	93.0 1.6	92.1 1.7	94.7 1.1	92.8 1.5
4. Josaeng Tong-il	8/13	79.6 1.3	80.3 1.9	68.7 1.1	79.0 3.1	86.9 1.3	89.5 3.4
5. Stirpe 136 Anthocyane	8/ 6	56.1 1.3	75.6 3.6	79.1 4.9	73.5 2.6	78.5 0.5	84.9 2.3
6. BG-1	8/11	80.1 0.3	82.4 3.5	89.4 0.7	87.7 1.1	86.5 1.1	88.6 1.0
7. Senshou	8/ 7	79.2 1.4	83.4 2.3	76.5 2.7	78.4 1.5	80.3 1.5	92.1 0.8
8. Sankanka	7/31	42.9 1.4	45.8 0.8	51.5 7.0	37.8 2.9	48.7 1.9	51.0 2.7

*1 : See text. *2 : Mean value. *3 : Standard error.

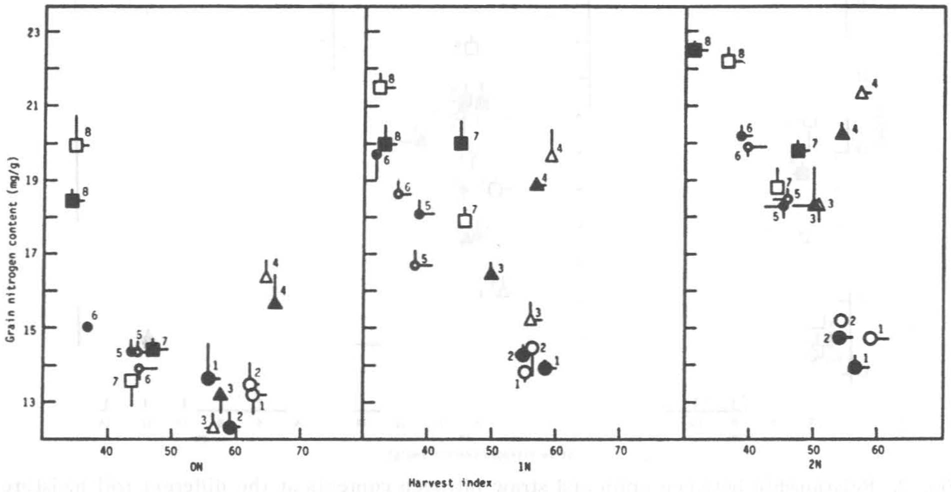

Fig. 1. Relationship between grain nitrogen content and harvest index at the different soil moisture and fertilizer levels.
Symbols : Open ; Upland condition.
Closed ; Flooded condition.
See Table 1 for cultivar number.
Horizontal and vertical bars indicate standard error×1/2, being applied to the following figures.

Correlation coefficients between grain nitrogen content and harvest index.

Moisture condition	Fertilizer level*	All Cultivars**	Excluding Josaeng Tong-il
Upland	0 N	−0.482	−0.725*
	1 N	−0.575	−0.899**
	2 N	−0.604	−0.961**
Flooded	0 N	−0.566	−0.877**
	1 N	−0.701*	−0.889**
	2 N	−0.767*	−0.925**

*See text, **See Table 1.

due to relatively large sink size to source size. In turn, this implies that Josaeng Tong-il has some genes which may cut-off the negative correlation between GNC and HI.

It was indicated that straw nitrogen content (SNC) was positively correlated with GNC[7]. However, the present experiment showed that SNC was not related with GNC, i. e. positively in some cases and negatively in other cases, in all the conditions although SNC of all the cultivars increased with fertilizer application (Fig. 2). This indicates that SNC which shows few varietal differences through all the conditions is not a source of the striking varietal differences of GNC. On the other hand, GNC tended to be positively correlated with total straw nitrogen content in all the conditions although the coefficients were low and showed 5 % significance (r=0.717) only at the 2 N level of fertilizer under lowland conditions (Fig. 3). This may indicate that nitrogen of a part of plant, e. g. lower (old) leaves which would die and fall out is translocated to the grains, and SNC of physiologically active part, e. g. upper (young) leaves retains a characteristic level of nitrogen content for each cultivar.

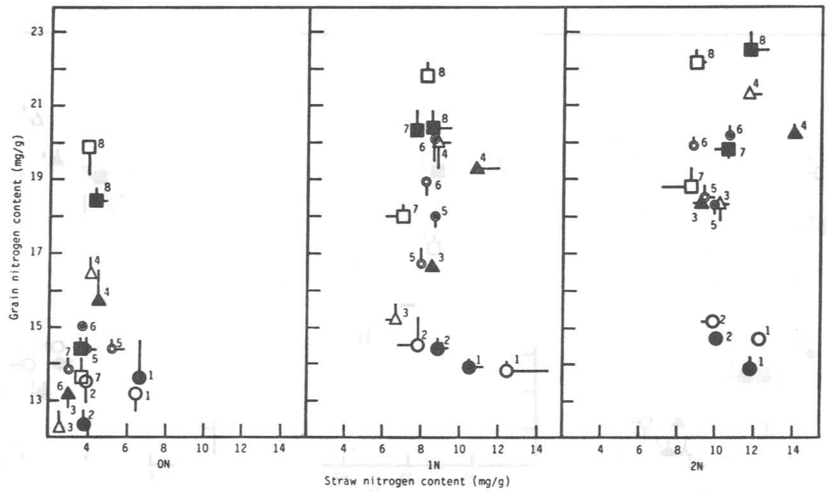

Fig. 2. Relationship between grain and straw nitrogen contents at the different soil moisture and fertilizer levels.
See Fig. 1 for symbols, and Table 1 for cultivar number.

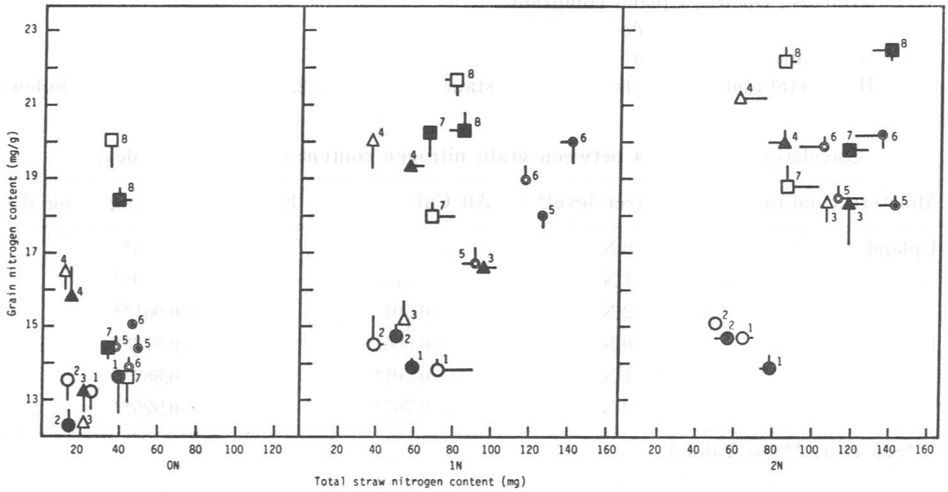

Fig. 3. Relationship between grain nitrogen content and total straw nitrogen content at the different soil moisture and fertilizer levels.
See Fig. 1 for symbols, and Table 1 for cultivar number.

Correlation coefficients between grain nitrogen content and total straw nitrogen content.

Moisture condition	Fertilizer level*	All cultivars**
Upland	0 N	0.215
	1 N	0.293
	2 N	0.343
Flooded	0 N	0.323
	1 N	0.420
	2 N	0.717*

*See text, **See Table 1.

Fertilizer application was effective for increase of GNC as reported by De DATTA (1981) with slight decrease of HI. However, a contrasting difference of response to fertilizer application was observed among cultivars. That is, the two *Japonica* cultivars were lower in their increase in the rate of grain nitrogen with increase of fertilizer level than the others.

Soil moisture brought about only a slight difference of GNC and HI in all the fertilizer levels, and influenced GNC in different ways among cultivars. This may indicate no effect of soil moisture on change in GNC. However, grains of upland crops, e. g. wheat and corn, have higher protein content than rice grains. The high grain protein content in upland crops may be ascribed to the fact that the upland crops reach the highest level of physiological plant activity such as photosynthesis at flowering[12]. Thus, the upland crops may be able to maintain nitrogen absorption throughout the grain filling period, resulting in a high grain protein content. In contrast, the highest physiological plant activity in rice plant attains at about young panicle formation stage, and then decreases rapidly[11]. This fact may be due to the decrease of root activity with the increase of soil reduction at the high soil temperature in the summer season. Thus, the decrease of plant activity of rice during the grain filling period would bring about the low grain protein content. No effect of soil moisture on the grain protein content may be due to a long adaptation to flooded conditions. That is, the rice plant has acquired the morphologically and physiologically tolerant traits[1] against the soil reduction. However, the rice plant appears to be unable to retain the ability of root to actively absorb the nitrogen fertilizer during the grain filling. Therefore, the next strategy to increase the grain nitrogen content is to breed the more tolerant rice against the soil reduction.

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肥料及び土壌水分の水準を異にした場合の玄米の窒素含量の遺伝変異

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摘　要

一般に，玄米の窒素含量と収穫指数との間には負の相関が観察される．これは，収穫指数が高い場合窒素が玄米中で希釈されるためであるとされている．しかし，本研究で使用した日•印交雑種の早生統一 (Josaeng Tong-il) は，玄米の窒素含量と収穫指数の双方とも高く，玄米の窒素含量と収穫指数との間の負の相関関係を断ち切る遺伝的特徴を有することが示唆された．更に陸稲の山稈禾は，肥料水準が低い状態でも玄米の窒素含量が高い傾向を示した．ただし，この品種の不稔歩合が高く，そのため玄米の窒素含量が高くなったともみられ，この点は今後の研究に残された．一方，玄米の窒素含量は，単位藁重当り窒素含量とは何等の関係を示さなかったが，全藁窒素含量とはやや高い相関を示した．それ故，大きな窒素貯蔵容量(藁)を有する品種は，転流によって玄米の窒素含量を高める利点があると推察される．